Research on Gravity Interpolation Technology for RAPINS/Log/Gravity Matching Integrated Navigation System

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Abstract

Rate azimuth inertial platform/Log/Gravity matching is a simple passive navigation system, the high resolution digital gravity anomaly map is essential for this system. The five kinds of gravity anomaly interpolation are introduced, which include bilinear interpolation, Shepard method, gravitational abnormal approximation based on the distance and direction, the improving Shepard method with the characteristics of band, and the improving Shepard method based on adjacent type value point. The corresponding gravity maps of these methods are given, the simulations of different gravity interpolation for RAPINS/Log/gravity matching integrated navigation system are carried out, and the results shows that the different gravity anomaly fitting methods have some influence on the navigation precision, but can limit position error to several grids.

Keywords: gravity map, gravity navigation, interpolation

Introduction

A new underwater passive gravity navigation system of RAPINS/Log/gravity matching is composed of a rate azimuth platform inertial navigation system (RAPINS with moderate precision accelerometers and gyroscopes) [1], a gravity sensor on the rate azimuth platform, a digital gravity map, and a log[2], so it is simple and has low cost. This integrated system adopts kalman filter, which observation equation is based on comparing the measurement of gravity sensor with the gravity map, to estimate and correct navigation parameters error, so the high resolution digital gravity map is essential. Because the usually gravity measurement value is sparse[3], five kinds of gravity anomaly interpolation are given to obtain high resolution digital gravity map, and corresponding interpolation gravity maps are drawn in this paper. With gravity anomaly map whose resolution is improved to $0.005^{\circ} \times 0.005^{\circ}$ by different gravity interpolation, the simulation of RAPINS/log/gravity matching integrated system is carried out, and simulation results show that, applying different gravity interpolation, the positioning errors of the RAPINS/gravity matching integrated navigation system are varied, but can be limited effectively.

Gravity interpolation algorithm

The usually digital gravity abnormal resolution is very low, which cannot meet up with RAPINS/log/gravity matching integrated navigation[4]. Therefore, studying the spatial variation of gravity field and the interpolation algorithm, to obtain high resolution digital gravity map is needed.

Gravity approximation method based on Shepard

The distance between the interpolation point (φ, λ) and the type value point (φ_i, λ_j) is r_{ij} , then $r_{ij} = \sqrt{(\varphi - \varphi_i)^2 + (\lambda - \lambda_j)^2}$. Fitting with Shepard approximation method, the corresponding anomaly gravity interpolation points (φ, λ) can be expressed as,

$$g_y(\varphi, \lambda) = \sum_{i,j=1}^{M,N} \left(G_y(\varphi_i, \lambda_j) / r_{ij}^{\mu} \right) / \left(\sum_{i,j=1}^{M,N} \left(1 / r_{ij}^{\mu} \right) \right) \tag{1}$$

It can be seen that when using Shepard approximation method, abnormal gravity interpolation $g_y(\varphi, \lambda)$ is the weighted average of all type points' abnormal gravity values $G_y(\varphi_i, \lambda_j)$ $(i = 1 \cdots M, j = 1 \cdots N)$, and the weight of each type value point is decided by the distance from this type value point to the interpolation

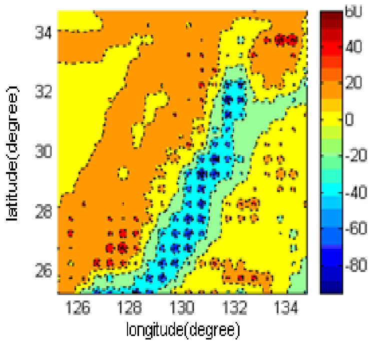


Fig.1Abnormal gravity of Shepard interpolation

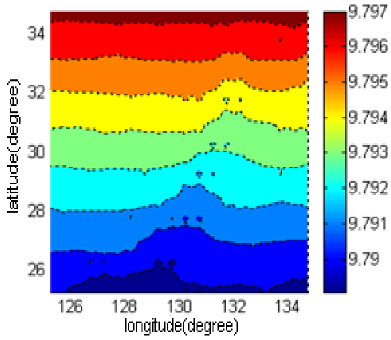


Fig.2 gravity of Shepard interpolation

Based on the abnormal gravity data resolution of $0.5^{\circ} \times 0.5^{\circ}$ between the region of $(125.25^{\circ}, 25.25^{\circ})$ and $(34.75^{\circ}, 134.75^{\circ})$ according to gravity field model of EGM96, the interpolation methods are tried to higher resolution of $0.005^{\circ} \times 0.005^{\circ}$. Using Shepard interpolation with $\mu = 2$, the corresponding anomaly gravity contour map and gravity contour map with higher resolution of $0.005^{\circ} \times 0.005^{\circ}$ are shown in fig.3 and fig.4, , which the abnormal gravity unit is mGal, the gravity unit is *m/s*^{2}. It can be seen that the distributions of abnormal gravity and gravity are all a bit of smooth, and there is quite a lot of the singular points because of gravity mutations.

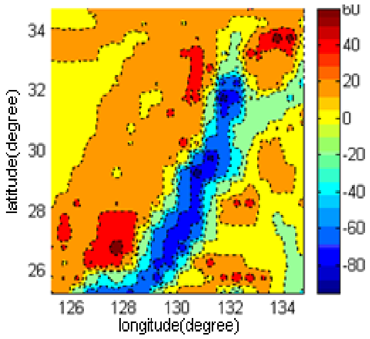
The improving Shepard method based on adjacent type value points

In Shepard method of Eq.1, the calculation of the interpolation function $g_y(\varphi, \lambda)$ need to consider all the type value points and its weight, so the amount of calculation is very large, and for a very large surface, using r_{ij} to calculate the distance between the interpolation point and the type value points is not appropriate. In order to improve the computing speed, and reduce the calculation error, in this paper, the Shepard method is improved, which uses several adjacent type value points to calculate $g_y(\varphi, \lambda)$. The improved Shepard method based on adjacent type value points is,

$$g_y(\varphi, \lambda) = \sum_{m,n=-a}^{a} \left(G_y(\varphi_{i+m}, \lambda_{j+n}) / r_{i+m,j+n}^{\mu} \right) / \left[\sum_{i,j=1}^{M,N} \left(1 / r_{ij}^{\mu} \right) \right]^{-1}$$

(2)

Where the position (φ_i, λ_j) is the most nearby type value point, and the position $(\varphi_{i+m}, \lambda_{j+n)}$ $(m, n = -a, \cdots, a)$ is the surrounding type value points. When $a = 1$, $g_y(\varphi, \lambda)$ is decided by the neighboring nine abnormal gravity values and their weighting functions. When $a = 2$, $g_y(\varphi, \lambda)$ is decided by the neighboring 25 abnormal gravity values and their weighting functions.



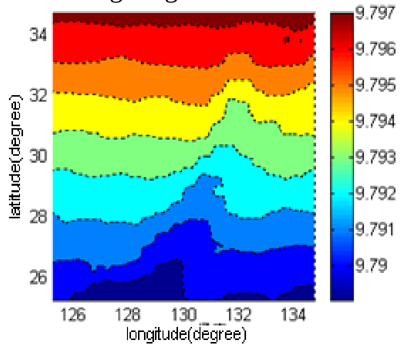


Fig.3Abnormal gravity of improving Shepard interpolation Fig.4 gravity of improving Shepard interpolation

Using the improving Shepard method based on adjacent type value point with $\mu = 2$ and $a = 1$, the corresponding anomaly gravity contour map and gravity contour map with higher resolution of $0.005^\circ \times 0.005^\circ$ are shown in fig.3 and fig.4. Comparing with fig.1 and fig.2, it can be seen that, fitting by the improving Shepard method based on adjacent nine type value point, singular points are significantly reduced, and the gravity anomaly map has obvious regional characteristics.

The gravitation abnormal approximation based on the distance and direction

In Shepard approximation Eq.1, the weight function is decided by only distance. If considering the direction, so the fitting method is based on distance and direction, when $r_{ij} \neq 0$, the corresponding anomaly gravity of interpolation points (φ, λ) can be expressed as,

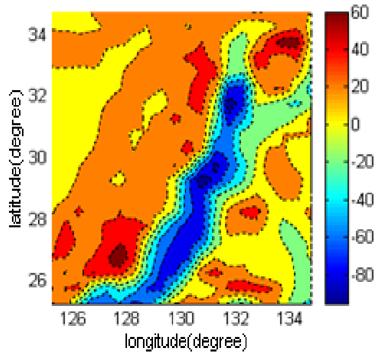
$$g_y(\varphi,\lambda)=\sum_{i,j=1}^{M,N}A_{ij}(\varphi,\lambda)\left[G_y(\varphi_i,\lambda_j)+(\varphi-\varphi_i)\frac{\partial G_y(\varphi_i,\lambda_j)}{\partial\varphi}+(\lambda-\lambda_j)\frac{\partial G_y(\varphi_i,\lambda_j)}{\partial\lambda}\right] \quad (3)$$

Where $\frac{\partial G_y(\varphi_i,\lambda_j)}{\partial\varphi}$ and $\frac{\partial G_y(\varphi_i,\lambda_j)}{\partial\lambda}$ are partial derivative along the latitude and longitude direction of the gravity type value points, $A_{ij}(\varphi,\lambda)$ is related to distance, and $A_{ij}(\varphi,\lambda)=\left[r_{ij}^{\mu}\sum_{i,j=1}^{M,N}\left(1/r_{ij}^{\mu}\right)\right]^{-1}$.

Applying approximation Based on the distance and direction with $\mu=2$, the corresponding anomaly gravity contour map and gravity contour map with higher resolution of $0.005^{\circ}\times0.005^{\circ}$ are drawn. The corresponding maps indicate that the abnormal gravity distribution and gravity distribution are relatively smooth, there are some abnormal gravity mutations singular points, and singular points are much less than Shepard interpolation method.

Double linear anomaly gravity approximation method

If the abnormal gravity values of the typical location (φ_i,λ_j) $(i=1\cdots M, j=1\cdots N)$ is $G_y(\varphi_i,\lambda_j)$ available, and the interpolation point P of the location (φ,λ) is not the typical location, the abnormal gravity values of P can be calculated by bilinear interpolation according to its neighboring four typical locations.



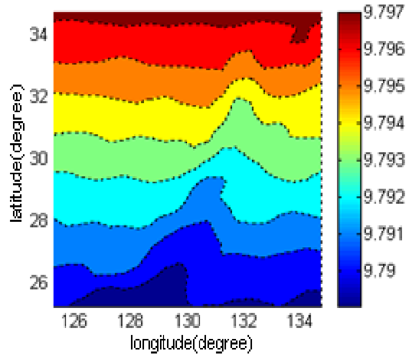


Fig.5Abnormal gravity map of bilinear interpolation Fig.6 gravity map of bilinear interpolation

When using bilinear interpolation, the anomaly gravity contour map and gravity contour map with resolution of $0.005^\circ \times 0.005^\circ$ are shown in fig.7 and fig.8. As you can see, depending on the bilinear interpolation, the distributions of abnormal gravity and gravity are all very smooth.

The improving Shepard interpolation with the band characteristics

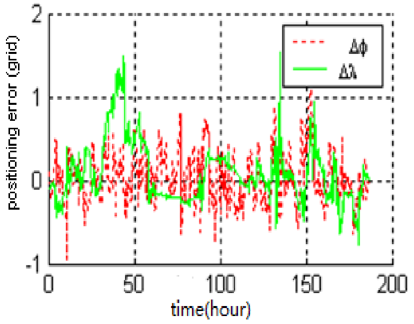
The improving Shepard interpolation with the band characteristics divides the fitting region of radius a into two band, and defines the weight function $P(r_{ij})$ respectively. When $0 < r_{ij} \le a/3$, $P(r_{ij}) = r_{ij}^{-1}$ where r_{ij} is the distance between the type value point (φ_i, λ_j) and interpolation point (φ, λ). When $a/3 < r_{ij} \le a$, $P(r_{ij}) = 27/(4a)(r_{ij}/a-1)^2$, and when $r_{ij} > a$, $P(r_{ij}) = 0$. The function $g_y(\varphi,\lambda)$ of the improving Shepard interpolation with the band characteristics can be calculated as,

$$g_y(\varphi,\lambda) = \sum_{i,j=1}^{M,N} G_y(\varphi_i,\lambda_j)\left(P(r_{ij})\right)^{\mu} \left[\sum_{i,j=1}^{M,N}\left(P(r_{ij})\right)^{\mu}\right]^{-1} \tag{4}$$

Using the improving Shepard interpolation with the band characteristics with $\mu = 2$ and $a = 0.5^\circ$, the corresponding anomaly gravity contour map and gravity contour map with higher resolution of $0.005^\circ \times 0.005^\circ$ are very coarse, which are close to the fitting based on distance and the direction, and have clearly band characteristic.

Simulation

When the carrier sails toward the north from position $(146^\circ, -45^\circ)$ at a constant speed of 20 *m/s.* Using bilinear interpolation to improve gravity resolution from $0.5^\circ \times 0.5^\circ$ to $0.005^\circ \times 0.005^\circ$, the positioning error curve of RAPINS/Log/gravity matching integrated navigation is shown in Fig. 9.



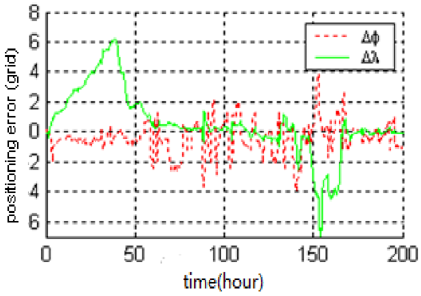


Fig.7 the bilinear interpolation position error

Fig. 8 the improving 9-dot Shepard positon error

When using Shepard method based on adjacent nine type value points, the navigation positon error is Fig. 10 . It can be seen that the interpolations have some influence on navigation precision, but but can limit position to several grid.

Summary

The high resolution gravity grid data is the precondition of RAPINS/log/gravity matching navigation system, five kinds of gravity interpolation methods are introduced, the corresponding interpolation result are compared by analysis and maps. The simulation shows that different fitting methods have some influence on the precision of RAPINS/log/gravity matching integrated navigation system.

Acknowledgments

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